CHAPTER 19

CIRCUIT PROTECTION

Chapter 18 explained how current in a circuit can be controlled by automatically opening and closing a set of contacts connected in series in the circuit. Controlling the time current flows in a circuit does not necessarily control the magnitude of the current. A circuit is installed to carry a maximum safe operating current, this being known as the rated current of the circuit. Currents in excess of this value can result in damage to both the equipment and the wiring of the circuit. Protection against continuous small and large over-current conditions in a circuit is provided by the installation of fuses and/or circuit breakers at the starting point of the circuit.

20.1 THE 'SHORT CIRCUIT'

A common expression used in the electrical field is the term, a 'short circuit'. This implies that a condition of zero resistance exists in the circuit. Current needs a conductor between points of different potential before it can flow. Conductors must always contain some resistance to the flow of electrons, even through this value may be very small. The source itself consists of current carrying components which cause a source to possess an internal resistance (r_i), while the conductors connecting a source to a load will also contain resistance (r_c).

In a d.c. circuit containing a source, connecting cables and a load (Figure 19.1) each part of the circuit may be replaced with its equivalent resistance. (Figure 19.2).

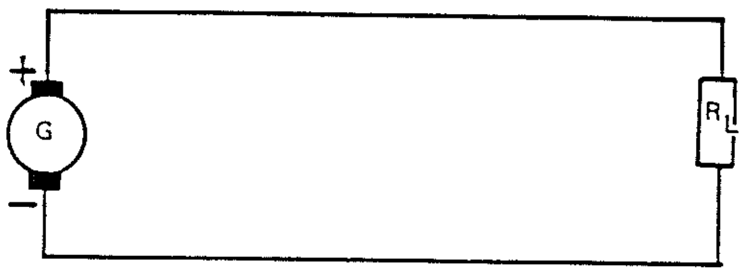


Figure 19.1

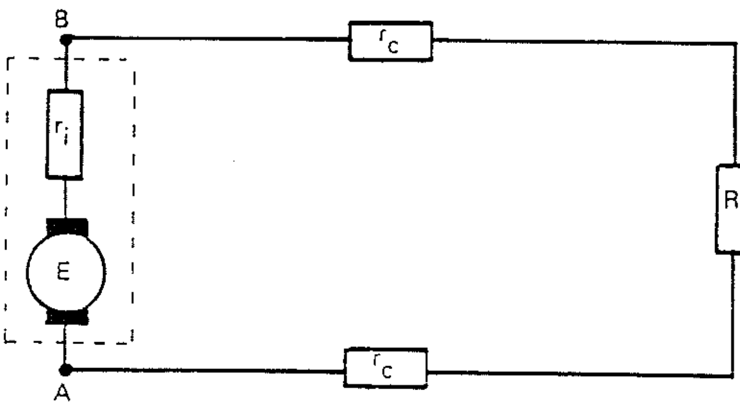


Figure 19.2

When Figure 19.1 is redrawn as Figure 19.2 the source and the connecting wires in Figure 19.2 are assumed to have zero resistance. The current in the circuit is then limited by the actual resistance connected across the source E, the minimum resistance being that of the internal resistance r_i. Faults, or short circuits may occur at the terminals of, or within, the load (R_L), along the connecting conductors; or at the terminals of the equivalent source (AB).

The magnitude of the current in the circuit is calculated by dividing the source voltage (E) by the total resistance in the circuit, looking back from the fault towards the source of supply.

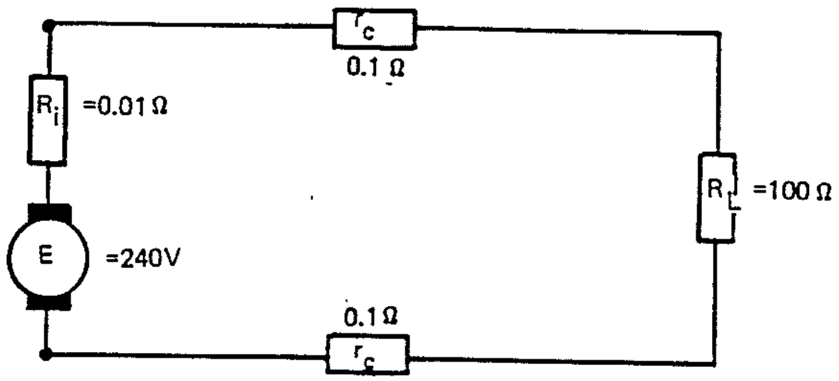
Example 19.1

A 240 volt d.c. generator has an internal resistance of 0.01 ohms. The generator is connected to a load of 100 ohms by cables, each having a resistance of 0.1 ohms. Calculate the current delivered by the source when -

(a) normal operating conditions apply

(b) the load terminals are short circuited

(c) the generator terminals are short circuited



$E = 240\ V$

$r_i = 0.01\ \Omega$

$R_L = 100\ \Omega$

$r_c = (2 \times 0.1)\ \Omega$

(a) Total resistance $= r_i + 2\,r_c + R_L$

$= 0.01 + (2 \times 0.1) + 100$

$= 100.21$ ohms

$I = \dfrac{E}{R}$

$= \dfrac{240}{100.21}$

$= 2.395\ A$

(b) Total resistance $= r_i + 2\,r_c$

$= 0.01 + 0.2$

$= 0.21$ ohms

$I = \dfrac{E}{R}$

$= \dfrac{240}{0.21}$

$= 1142\ A$

(c) Total resistance $= r_i$

$= 0.01$ ohms

$I = \dfrac{E}{R}$

$= \dfrac{240}{0.01}$

$24000\ A$

From these calculations it can be seen that currents far in excess of rated current, may be drawn from a source of supply for a brief instant if certain condions exist in a circuit. These faults can cause dangerous current surges within a circuit unless suitable protection is provided at the source.

19.2 FUSES

A fuse is a device which opens a circuit by the melting of a fuse element. It consists of three parts -

(i) The base, which is inserted in series with a circuit

(ii) The wedge, which contains the fuse element

(iii) The fuse element

The base is rigidly fixed, while the wedge can be removed from the base to allow easy and safe replacement of the fuse element. Fuses are rated by the current the fuse element will carry continuously without overheating. Fuses are of the rewirable or non-rewirable types. The rewirable fuse element is usually tinned copper wire. The tinning of the wire is to prevent oxidation of the copper, this oxidation altering the current carrying capacity of the wire. Most rewirable fuses have the base and wedge made from porcelain, a heat resistant material (Figure 19.3).

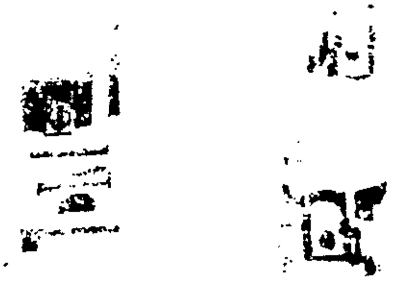


Figure 19.3

The porcelain material constrains the high temperature arc of the melting fuse element within the fuse, preventing possible damage to the immediate surroundings.

Non rewirable fuses use fuse elements called high rupturing capacity (H.R.C.) elements. The element is completely encased in a ceramic cartridge. (Figure 19.4).

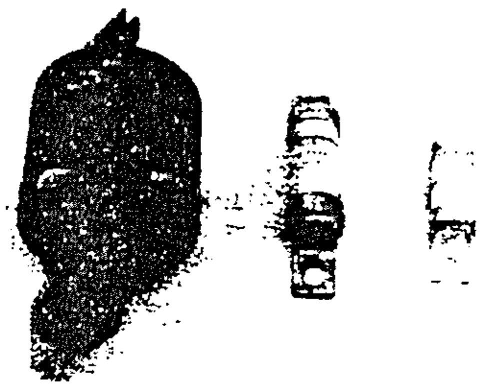


Figure 19.4

Also included in the cartridge is a heat absorbing silica powder. While the fuse element for a rewirable fuse is a single strand of tinned copper wire the element for a H.R.C. fuse is made of silver and is produced in various shapes. (Figure 19.5).

Figure 19.5

The elements will always melt at the points where their cross-sectional areas are the least.

The design of the fuse element, its material, and the fact that it is not subject to oxidisation, (because it is totally enclosed) leads to a high degree of accuracy in circuit protection. As all the heat is retained within the cartridge, the base and wedge need not be made of heat resistant material. This allows for the introduction of the more durable and decorative plastic moulded fuse base and wedge. (Figure 19.6).

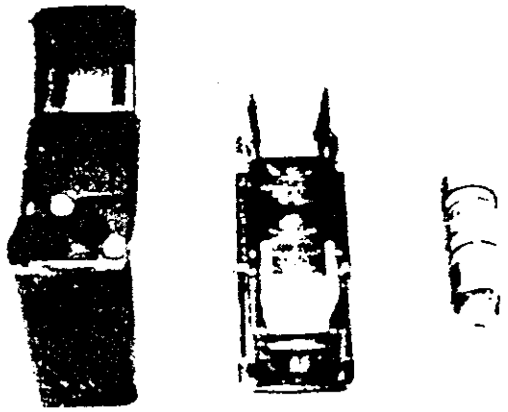


Figure 19.6

Rewirable fuses are far cheaper than an equivalent rated H.R.C. fuse. The cost of replacing H.R.C. fuse elements is high compared to a copper wire element. Non rewirable fuses are used extensively where the degree of accuracy in circuit protection is not important. Typical applications are domestic dwellings and factories. A disadvantage of the non-rewirable fuse is that it can easily accept a fuse element far in excess of its own rating, resulting in possible damage to the equipment connected to the circuit or even fire if a sustained overcurrent condition is continued. While the H.R.C. fuse is more expensive than the rewirable fuse it is also far more reliable under fault conditions.

9.3 CIRCUIT BREAKERS

Switches which incorporate a feature to open automatically under certain desired conditions are known as circuit breakers. Circuit breakers are principally designed to protect cables or more specifically the insulation of the cable but must also operate to protect the equipment. A circuit breaker must conform to the SAA code No. AS3000 which defines the following minimum operating characteristics.

1. It must have an inverse time tripping characteristic on overloads up to about 10 time its rated current, so that it will trip faster on heavy overloads than on light ones.
2. It must trip instantaneously on overloads above about 10 times rates current so that it will cut off short circuit currents as quickly as possible.
3. On any overload up to 10 times rated current its tripping time must become smaller as the temperature increases so that even in very hot weather the maximum temperatures allowed on the cable insulation will never be exceeded.

These three characteristics will be referred to by their identifying numbers, i.e., 1, 2, and 3, when the various types of tripping elements are discussed.

A graph illustrating points 1 and 2 is shown in figure 19.7.

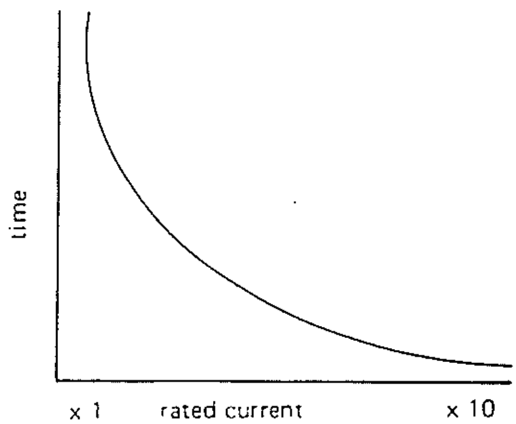


Figure 19.8

As the current increases the tripping time decreases.

Circuit breakers are classified by the type of tripping element they employ.

19.4 TYPES OF TRIPPING ACTIONS (Courtesy Email)

There are five main types of tripping units:

(1) a thermal type;

(2) a magnetic type;

(3) a combination of types 1 and 2 known as a co-operative thermal-magnetic type;

(4) current limiting types;

(5) solid state type.

Only the first three will be examined in this chapter as the other two are more involved and are included in later studies. Figure 19.8 illustrate the mechanisms involved in the three tripping actions.

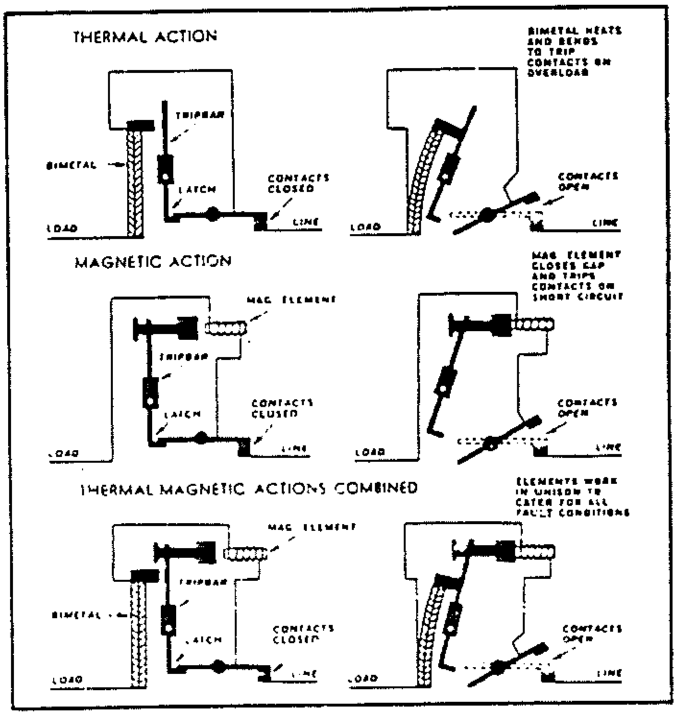


Figure - 19.8

(1) Thermal Type

This type relies for its operation on the heating effect of the current and utilises a bimetallic element to convert heat into mechanical movement. When a piece of bimetal is heated it bends because it consists of two pieces of metal welded together, the two metals expanding at different rates when heated. In directly heated thermal trip units, the current actually passes through the bimetal, the combination of the current and the electrical resistance of the bimetal producing the necessary heating. In indirectly heated thermal trip units, the current passes through a heater, placed close to the bimetal so that some heat is transferred ot it, i.e., no current flows through the bimetal itself. Both directly and indirectly heated thermal trip units are used in breakers, the former generally on breakers up to about 50 amperes rating and the indirectly heated type on larger breakers.

In both types of thermal trip unit, the bimetal is connected to a latch piece which normally is in such a position that the switching mechanism is 'latched' and the breaker can be closed and opened manually. However, as the bimetal heats and bends, the latch piece moves and after moving a certain distance it releases the mechanism and automatically opens the contacts. The bimetal can be adjusted so that the breaker opens at any current up to 10 times rated value, in a sufficiently short time to prevent the maximum cable insulation temperature from being exceeded. Thus the thermal trip unit meets the first characteristic of the ideal circuit breaker as stated above.

Above 10 times rated current the bimetal still takes a definite time to heat up and unlatch the breaker. A thermal trip, therefore, does not trip the breaker instantly and does not meet the second requirement.

Even when no current is flowing through the breaker, an increase in ambient temperature affects the bimetal causing it to move away from the latch point, and if this temperature becomes high enough, the breaker will ultimately trip. Hence, at high temperatures the bimetal has already moved through portion of the distance necessary to trip the breaker and it will not take as long for the heat produced by the current to move it the remaining distance and allow the breaker to open automatically. Tripping times of a thermal trip unit, therefore, decrease as the ambient temperature increases which is exactly what is required in number three characteristic of an ideal breaker.

(2) Magnetic Type

The magnetic type of trip works on an entirely different principle. It consists of an electromagnetic coil consisting of a number of turns of wire through which the current passes. Inside the coil at one end is an iron slug or plunger. At the other end is a spring-loaded magnetic element on wh ich the latch is mounted.

Light overloads do not produce a magnetic field strong enough to overcome the spring action of the latch piece, but the field does cause the iron plunger to move towards the other end of the coil. On reaching the other end, the iron plunger increases the magnetic pull which is then strong enough to pull the latch piece against its springs and to trip the breaker. The movement of the plunger is slowed down by making it force air or a liquid from a cylinder through a small orifice. This is known as a dashpot and provides the required time delay. By correctly shaping the hole and varying the number of turns on the coil it is possible to provide breaker tripping times at various currents which will prevent maximum cable insulation temperatures from being exceeded at one **specific ambient temperature.**

On heavy overloads, the magnetic field is strong enough to move the latch piece without the assistance of the iron plunger. For all practical purposes the breaker opens instantaneously. Hence, a magnetic trip meets requirement number 2.

As stated above, a magnetic trip can be adjusted to prevent maximum insulation temperatures from being exceeded at any specific ambient temperature. Unlike a thermal trip, the operating times of a magnetic trip do not vary appreciably with temperature. The tripping time for an overload is more or less the same at all temperatures. This means that if the tripping times are adjusted to prevent maximum insulation temperatures from being exceeded at normal room temperatures, thenat high air temperatures the maximum insulation temperature will be exceeded. The breaker tripping times are unchanged, but it does not take as long for the cable insulation to reach this maximum temperature. Hence, a magnetic trip beaker fails on requirement number 3

(3) Co-operative Thermal Magnetic Type

This type of trip action is actually a combination of the previous two. On low overloads, only the thermal action operates providing both time delay and variations in tripping times with temperature. However, at about 7 to 8 times rated current, the magnetic element starts to play its part and speeds up the operation of the thermal trip. This is why it is known as a co-operative thermal magnetic trip. At currents of about 10 times rated value and higher, the magnetic trip completely overrides the thermal action and opens the breaker instantaneously. The action of the co-operative thermal magnetic trip is illustrated in Figure 3.

Hence, the co-operative thermal magnetic trip, by combining the desirable features of both the thermal and the magnetic types, meets all three requirements of the ideal circuit breaker.

Summary

The relative merits of each type of trip action may be summarised in the following table:

	Thermal	Magnetic	Co-op Thermal Magnetic
Inverse Time characteristic	Yes	Yes	Yes
Instant Tripping on short circuits and heavy overloads	No	Yes	Yes
Variation of trip times with air temperature	Yes	No	Yes
Total number of desirable features	2	2	3

Note that the co-operative thermal magnetic trip is the only one which provides all three essential features of a complete protective device. Neither a thermal trip nor a magnetic trip performs a complete protecting job. Both will allow cables to be overloaded under certain conditions whereas a thermal-magnetic trip will protect the cable all the time, irrespective of the current and the temperature.

19.5 'TRIP FREE' OPERATION OF CIRCUIT BREAKERS

On most circuit breakers the manual operating handle also serves to indicate whether the breaker contacts are closed, open through manual operation or open as a result of automatic tripping. The last case is indicated by the handle being in a position, midway between the 'on' and 'off' positions as shown in Figure 19.8. This distinct 'tripped' handle position is a most desirable feature particularly where breakers of a fault in its circuit. All circuit breaker handles are 'trip free', which means that if the handle is held or locked in the 'on' position, the breaker will still trip open in the event of a circuit fault.

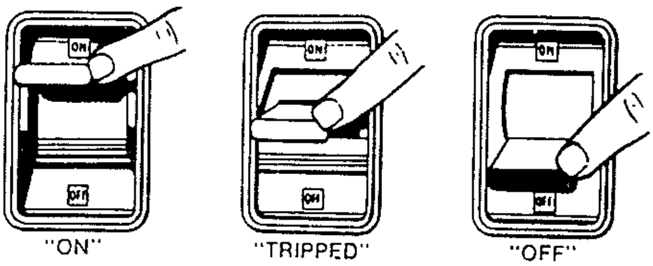


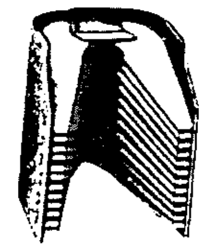
Figure 19.9

19.6 ARC EXTINGUISHING

When the circuit breaker breaks a heavy fault current, an arc is drawn between the contacts as they open. Some large breakers incorporate two sets of contacts, one to carry the current when the breaker is closed, the arc being drawn between the other set when the contacts open. In this way the main contacts never have an arc drawn between them, so that they suffer little damage. The arc which is formed, particularly on short circuit current, can cause great damage, if allowed to persist even for a short time. Some means of quickly extinguishing the arc is essential, and to meet this requirement various devices have been produced. Some rely on stretching the arc to a point where it cannot maintain itself. This process is relatively slow. The most successful device, known as a 'De-ion' grid was developed in 1927, by Dr Joseph Selpian of the Westinghouse Research Laboratories near Pittsburgh, U.S.A.

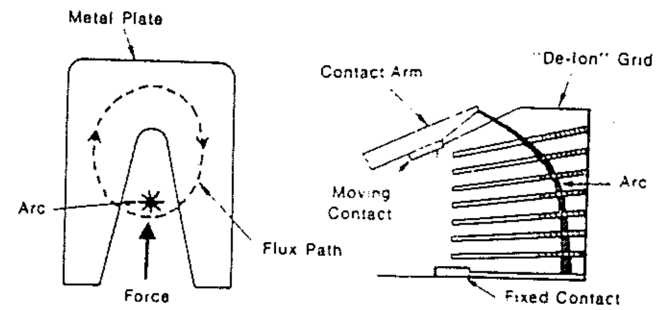
The 'De-ion' grid consists of a series of specially shaped steel plates which are held, with spacing between them, by fibre or ceramic supports. A typical 'De-ion' grid is shown in Figure 19.9.

Figure 19.10



The operation of the grid can best be understood by studying Figure 19.10. When the arc is initially drawn between the contacts, a circular magnetic field is set up around it, in an identical manner to the field produced by a current flowing in a wire. The steel plates in the grid distort the circular shape of the field, as the field tends to follow the form of the U– shaped plates. The resulting magnetic field is similar to that produced by a horseshoe magnet.

Figure 19.11



The field then cuts across the arc drawn between the contacts, forcing it by magnetic action in the direction of the arrow, into the grid. The metal plates 'chop' up the arc into a number of small arcs which are self extinguishing. The steel, being a good conductor of heat, rapidly cools the arc and materially assists in extinguishing it in a very short time. A 'De-ion' grid is capable of quenching an arc in as short a time as ¼ cycle or .005 seconds.

Arc extinguishing devices of the 'De-ion' grid type are almost universally used in moulded case type circuit breakers.

TUTORIALS 1.19

(1) A 250 volt 10 kW d.c. load is supplied from a generator, whose internal resistance is 1 ohm, through cables each having a resistance of 0.5 ohms. Calculate:-

(a) the normal load current

(b) the fault current if the load terminals are short circuited

(c) the fault current if the generator terminals are short circuited

(2) A d.c. generator supplies a 50 kW load at a t.p.d. of 250 volts through connecting cables which each have a resistance of 0.1 ohms. Calculate the t.p.d. of the generator.

(3) A 250 volt generator delivers 25 kW to a d.c. load whose t.p.d. is 240 volts. Calculate:-

(a) the power loss in the connecting cables

(b) the total resistance of the cables

(4) A heating load is connected to a d.c. generator whose t.p.d. is 240 volts. The internal resistance of the generator is 0.25 ohms and the total resistance of the connecting cables is 0.5 ohms. Calculate the current delivered by the generator if:-

(a) a load of 48 kW is supplied

(b) the load terminals are short circuited

(c) the generator terminals are short circuited (neglect voltage drops in the cables)